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(54) **Color matrix display apparatus and method for designing said apparatus.**

(57) An optical reconstruction filter in the form of a phase diffraction grating (31) (that is, a diffractive diffuser) placed between a flat panel liquid crystal color matrix display (30) and a viewer to optically filter flat panel images and present a higher quality image to the viewer.

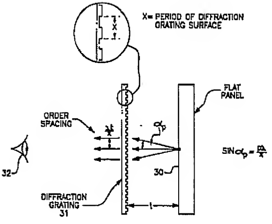


*Fig. 4*

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# COLOR MATRIX DISPLAY APPARATUS AND METHOD FOR DESIGNING SAID APPARATUS

The present Invention is related to a color matrix display apparatus according to the preamble of claim 1 and to a method for designing it.

In particular this invention is directed to the area of optical reconstruction filters for color mosaic (matrix) displays as e.g. flat panel liquid crystal displays.

## Background

The use of flat panel color matrix displays is increasing rapidly. These displays have regular structures of color pixels, as for example is shown in Figure 1, which are used to create the color image. An existing problem is that the dotted and discontinuous appearance of images shown on color mosaic displays is not desirable and needs improvement. That is, the underlying grid structure results in objectionable visual artifacts commonly referred to as sampling noise. Examples of sampling noise are pixel edges and gaps. These artifacts cause flat panel color matrix displays to have noticeably lower image quality than CRTs, rendering them inadequate for many situations.

This problem of visible dot structure in color matrix displays can be viewed as a two-dimensional image processing situation, which can be understood more easily by comparing it to its one-dimensional analog as shown in Figure 3. Segment 3a of Figure 3 shows an ideal signal (image) which is to be processed. An initial filter, the anti-aliasing filter, 3b, is used at the outset to limit the bandwidth of the ideal signal to frequencies the processing system can handle. Frequencies that are too high result in spurious noise and moire patterns.

The cutoff frequency of the anti-aliasing filter is determined, by sampling theory, to be at one-half of the frequency the system uses to sample the incoming signal. The system in the two-dimensional case consist of an image generator and color matrix display device. This cutoff frequency is commonly referred to as the Nyquist frequency. The output of the anti-aliasing filter is the actual signal (image) to be entered into the system, as shown at section 3c. The signal (image) is then digitized through an A/D converter (image generator), shown at section 3d, and is ready to be transferred to the rest of the system.

At the other end of the system, the digital signal (image) passes through a D/A converter, shown at section 3e. The output waveform of the D/A, shown at section 3f, is a signal (image), with undesirable high frequency noise present. The noise is due to the underlying sampling grid and results from an incomplete reconstruction process. To complete the process, the signal is passed through another filter, the reconstruction filter, shown at section 3g, with its cutoff again determined by the Nyquist criterion. At this point, assuming ideal filtration has been accomplished, the output shape shown at section 3h, is identical to the system input at section 3c.

All color matrix displays, intentionally or not, have relied on one of two types of optical reconstruction filters; 1) the eye itself with its associated low pass filter characteristics, or 2) a diffuse, or scattering, optical surface.

The eye as a reconstruction filter does not work satisfactorily for current flat panel display resolutions. For example, present color matrix displays typically have pixels 0,015 to 0,02 nm (6 to 8 mils) across. Human factors experiments have determined these pixel sizes result in sampling grids all too easily seen by the eye. The frequency content of the color matrix display structure, the display sampling grid, is clearly well within the bandpass characteristics of human vision. The eye cannot filter out spatial frequencies this low at typical viewing distances. The resolution of color matrix displays must increase significantly before the eye alone will be a sufficient low pass filter. This, however, is the reconstruction filter most often used for color matrix display applications.

Some color matrix display applications have used a diffuse scattering surface to eliminate sampling grid artifacts. A diffuse surface scatters the light, giving it optical low pass filter characteristics. The more scattering the surface accomplishes, the more diffuse the filter, and the more it smooths the image.

A common example is the diffuse picture glass frequently placed over photographs to reduce specular reflections.

Some optical low pass filtering results as well. Sudden luminance changes are attenuated giving the image a softer, smoother look. But, while eliminating specular reflection and while softening the image, these filters exhibit strong diffuse reflections of ambient light. The more a filter diffuses, the more light is

In display applications, even small amounts of reflected ambient light are objectionable. In higher ambients the diffuse reflections wash out the image altogether, rendering it unviewable. To get the amount of diffusion needed to eliminate the sampling noise of present color matrix display technology, the reflections become unacceptable, especially for cockpit display applications.

Another drawback of diffuse filters is that their passband characteristics are not tailorable over direction. The cutoff frequency is the same in all directions. For typical color matrix displays, whose underlying grid structure is not circularly symmetric, a filter with passband characteristics tailorable over direction is extremely desirable. Otherwise, the full frequency capability of the color matrix display is not taken to full advantage. Too much filtering will be exerted in some directions and/or too little will be exerted in others. Ideally, the low pass profile will exhibit characteristics determined directly by the color matrix display's own two-dimensional frequency capability.

It is the object of the present invention to devise a color matrix display apparatus having improved image quality. This object is achieved by the characterizing features of claim 1. Further advantageous embodiments of said apparatus may be taken from the dependent claims. A method for designing the filter used in said apparatus is subject of an independent claim.

## Summary of the Invention

The invention is a diffraction grating filter with defined spatial frequency passband characteristics, used to eliminate noise generated by color matrix dot structure.

The invention uses sampling theory to determine the frequency capability of the particular display. This is found by determining the Nyquist boundaries in two dimensions covering the surface of the display. The invention applies these two-dimensional boundaries to define the extent of traditional interpolation functions. Finally, the invention physically embodies these interpolation functions in the form of a phase diffraction grating in conjunction with the filter characteristics of the eye. The phase diffraction grating (may be a binary step type) is then applied over the surface of a color mosaic display to alter the point spread function of each pixel.

Subsequently, the luminance contained in each sample is distributed as a function of the distance from the sample point as defined by the interpolation function. Accordingly, information contained in each sample is added with information of surrounding samples of like primary hue to provide continuous luminance functions for each primary color. A higher fidelity representation of the desired output signal results. Continuity of the image function can be made through 1st, 2nd and higher order derivatives, depending on which interpolation function is selected to be embodied in the diffraction grating. Recognizing the lattice structure of each primary color is a key element of this invention. It can be applied to color mosaic patterns in general, including stripe, diagonal, delta, and quad pixel patterns.

That is, the invention provides continuity of the luminance functions of each primary hue on a color mosaic display in order to improve the image quality of sampled images. In the invention, a diffraction grating used as an optical reconstruction filter for color matrix displays, uses the phenomenon of diffraction to filter the image, instead of using scattering. The diffraction grating breaks each pixel image up into the various diffraction orders as it passes through the grating. These orders can be made to overlap and fall off in intensity, as shown in Figure 5. The diffracted pixels overlap and cause interpolation among the pixels of like color, getting rid of the high spatial frequency grid noise. The exact interpolation function used is determined by the position and intensity of the diffracted orders, which is, in turn, determined by the geometry and period of the diffraction grating structure, and the refractive index of the material.

Using the diffraction grating as a reconstruction filter is very advantageous for display applications. By using diffraction instead of scattering, reflections from the filter are specular instead of diffuse. These reflections still need to be handled, but they are easier to manage than diffuse reflections. Specular reflections can be cut down to less than 0.5% with standard optical anti-reflection coatings. Destructive interference techniques can be used to cut the reflections down even further.

In addition, the diffraction grating can be tailored to give the desired passband characteristics and interpolation functions. The passband characteristics of the filter need not be constant over direction. The almost infinite range of order intensities and positioning gives the designer freedom to choose the best interpolation functions for the job. Figure 12 shows some common interpolation functions, all of which would smooth the flat panel images. The surface profile of the diffraction grating can be designed to create these interpolation functions. This allows the reconstruction filter to be tailored to the exact structure of the color

The invention is easily incorporated into the color matrix display structure. The filter is etched in glass and can be bonded to the front of the panel or even made in the flat panel substrate glass. An example of the structure of the flat panel color matrix display together with the diffraction grating reconstruction filter proximate in front of it is shown in Figure 18.

## BRIEF DESCRIPTION OF DRAWINGS

Figure 1 shows a portion of a color matrix display including the individual pixels used to create an image on the display. The pixel pattern shown is the RGB delta matrix pattern.

Figure 2 illustrates the problem of sampling noise on color matrix displays. The figure shows two images, one using the diagonal pixel pattern, the other using a quad-green pixel pattern. Each of these images is anti-aliased. Discrete pixels can still be distinguished, as well as the gaps between pixels. A reconstruction filter is needed to eliminate these grid structure artifacts.

Figure 3 shows the analogy between the signal processing model and the image processing model, showing how a low pass reconstruction filter is needed between the display and the eye.

Figure illustrates how the point image on a flat panel is spread out by the diffraction grating.

Figure 5 shows how the original square pixel luminance is spread out and smoothed by diffraction. As more orders are used, the resulting diffracted pixel becomes smoother.

Figure 6A illustrates how light breaks up into orders after passing through a diffraction grating where p = order no.

Figure 6B illustrates a diffraction pattern of light through a two-dimensional diffraction grating where p,q = order no.

Figure 7 is a photograph of a laser beam passing through a diffraction grating and breaking up into orders. x = 100 lines/mm, y = 100 lines/mm.

Figure 8 shows a diagonal matrix pattern with the red primary lattice structure superimposed.

Figure 9 shows the spatial sampling array for a single primary color on the diagonal matrix pixel pattern.

Figure 10 illustrates the spatial frequency array for a single primary color on the diagonal matrix pixel pattern, and the corresponding Nyquist boundaries.

Figure 11 shows the ideal low pass transfer function for the diagonal pixel pattern, corresponding to the Nyquist boundaries of Figure 10.

Figure 12 waveforms a through f shows some common interpolation waveforms. The sinc waveform is the ideal, giving perfect reconstruction, but it is difficult to obtain. Figure 12 waveforms g, h and i show resulting interpolations. Thus, waveforms g, h and i show examples of signal reconstruction using the ideal sinc function, and the triangle and pulse function.

Figure 13A gives an example of a one dimensional reconstruction of a single primary signal using the triangle interpolation function. The higher order interpolation functions give better reconstruction.

Figure 13B shows the ideal two-dimensional interpolation function, the sinc function. Since this function is difficult to obtain, the lower order interpolation functions such as cubic B-spline or gaussian are usually used.

Figure 14 shows a close-up of the surface profile for one embodiment of the invention, a phase diffraction grating designed for the RGBY quad pixel arrangement.

Figure 15 illustrates the resultant pixel luminance profile when a cubic B-spline interpolation function is applied to a diagonal color mosaic pixel, showing the relative length to width ratio.

Figure 16 is a picture of a diffraction grating reconstruction filter used over a color matrix display. This illustrates how the filter causes the individual pixel luminances to spread and smooth together, interpolating the image.

Figure 17 shows a process for making a diffraction grating with dichromated gelatin.

Figure 18 shows an example of flat panel color matrix display together with a diffraction grating reconstruction filter in front of it.

Figure 19 is a representation of a grating fabricated with the 100 line/mm mask, and

Figure 20 shows the pattern created when a laser beam is passed through the grating.

## DETAILED DESCRIPTION

As described earlier, the invention is a diffraction grating with defined spatial frequency passband

characteristics, to be used as a reconstruction filter for color matrix displays, especially liquid crystal including active matrix liquid crystal flat panel color matrix displays such as is described in EP-A 0 316 708.

The invention interpolates among luminance values stored at each pixel site and, in concert with the low pass characteristics of the eye, renders a continuous image in the domain of each primary color. In other words, a diffraction grating filter is used to reduce flat panel image artifacts such as gaps, staircasing and color aliasing. This filter which is placed over a flat display panel of hundreds of pixels, smooths and precisely spreads the luminance profile of each pixel. The diffraction grating has several characteristics which make it useful for display applications including a first that the light spread function is variable over direction, and a second that the non-scattering reflection characteristics make reflections easier to control.

Referring now to Figure 6A there is shown a diffraction grating 10, herein also referred to as a diffractive diffuser. The diffractive diffuser uses the phenomenon of diffraction, which is incident light breaking up into "orders" after passing through a periodic edge 11 of the diffraction grating. The zero, first and second orders are shown in the figure. The image passing straight through the filter is called the zero order. The images on either side of the zero order are the +1 and the -1 order. The next images on either side are the +2 and the -2 order. The angular relation 12 is shown in the form $\sin \alpha_p = \frac{pg}{x}$ where $p$ = order number and x = the grating interval.

In Figure 6B there is shown a two dimensional diffraction grating 20 having grating intervals x and y. For a two dimensional grating the diffraction pattern of light from the incident light beam is two dimensional as shown on plane 21. The letters p and q represent the order numbers in the two dimensions x and y. In actual case more than two or three orders may be used giving much smoother final image.

Figure 7 is a photograph of a two dimensional diffraction pattern produced by a laser beam passing through a diffraction grating and breaking up into orders where $x$ = 100 lines/mm and y = 100 lines/mm. The position and intensity of the various orders are determined by the geometry and period of the diffraction grating structure and the index variation of the material. In the case of the flat panel pixel image, the grating will be made such that the orders overlap and fall off in intensity, creating an image much more gaussian than the original "step" image of the pixel, as shown in Figure 5a-e. These diffracted pixels will overlap and cause interpolation between pixels. The characteristics of a diffraction grating can be designed to be a function of direction, so the light spread function can be tailored to the flat panel pixel pattern.

Referring now to Figure 5 where I represents intensity, and particularly to Figure 5a there is illustrated the original pixel image having an intensity represented by height $I_o$ and horizontal dimensions from -a to +a. The diffracted pixel orders change pixel luminance profile. Figures 5b, 5c and 5d illustrate the zero order, +1 and -1 orders and the +2 and -2 orders, respectively. Figure 5b illustrates the zero order with an intensity of $2I_o/5$ and dimensions from -a to +a. Figure 5c illustrates the +1 and -1 orders and shows an intensity of $I_o/5$ with horizontal dimension of 3a (that is from -3/2a to +3/2a). Figure 5d illustrates the +2 and -2 orders and shows an intensity of $I_o/10$ and dimensions of 4a. As relative intensity and position of diffracted order changes, the final pixel image changes. Figure 5e illustrates the diffracted pixel image. In actual case, more than two orders may be used giving much smoother final image.

There are several different types of diffraction gratings. These include amplitude or phase types, and transmissive or reflective types. There are several manufacturing techniques, including holographic, ruled, and photolithographic. For the flat panel diffractive diffuser of this invention, a phase transmission grating is preferred because it has the highest transmission. It may be a binary step type. In a phase grating, the active diffractive material is transparent, with thickness variation across the surface. Figure 4 is illustrative of how the image of a point on the flat image panel 30 gets spread out by a diffraction grating 31. The grating 31 will be positioned in front of the panel 30 as shown in Figure 4, with the viewer 32 looking at the diffracted image.

A two axis grating will be used. The axes of the grating is preferably oriented to the major axes of the flat panel pixel pattern. The profile of the grating in $x$ and y is determined such that the luminance of same color pixels is interpolated in each direction. The distance between same color pixels is usually not the same in both axes. This distance is also different for different pixel layouts, such as the diagonal layouts versus the quad layouts. The grating profile is therefore tailored to a panel with a specific pixel size, spacing and layout. In one embodiment the grating is designed specifically for the Hosiden 0,017 mm (6.7 mil) diagonal mosaic panel.

It will be seen from Figure 4 that a spacing or distance "t" is shown between flat panel 30 and diffraction grating 31. By controlling the spacing "t" the extent of interpolation desired can easily be obtained.

The diffraction grating 31 is effective to spread out the luminance profile of each pixel, interpolating [illegible] images. In designing the diffraction grating surface profile, the final pixel

luminance is a design factor. It has been determined that the actual shape of the interpolation function is not as critical as the amount of interpolation used to smooth out the flat panel image. For example, if the interpolation function spans several pixels, colors of individual pixels will blend together more effectively with neighboring pixels to alleviate a common complaint of liquid crystal flat panel displays that they show an objectionable amount of color bonding on misconvergence.

A current problem of the prior art is that pixel size and patterns result in a pointillist or dotted presentation of the image. Using any of a linear or gaussian or cubic B-spline shape for interpolation can eliminate or minimize the dotted appearance and produce a significant advance in the quality of the image. Care must be exercised so as to not introduce too much interpolation othervise excessive blurring or defocussing will be perceived. Fortunately, the extent of the interpolation can easily be controlled by altering the spacing between the diffraction grating 31 and the display panel 30.

Figure 1 shows the individual red, green, and blue pixels of a typical color matrix display. Figure 2 illustrates the pixel structure artifacts which can occur from this type of discrete image display system. Jagged transitions, on what are intended to be smooth lines detract from positional accuracy and, in the case of moving symbology, lines appear to move in a jumpy, discrete fashion. Ideally, the flat panel color matrix display would paint smoothly shaped symbols, which move in a smooth, analog manner and exhibit color purity. The diffraction grating, used as an optical reconstruction filter, is used to obtain this smooth image on a color matrix display. The manner in which the diffraction grating is used as a reconstruction filter for color matrix displays is explained in the following paragraphs.

Determining the desired spatial frequency passband characteristics of the reconstruction filter is key, and begins with recognizing the underlying lattice structure of the color matrix display to be used. For example, Figure 8 shows a diagonal matrix pattern with the red primary lattice structure superimposed. This lattice structure determines the spatial sampling array of the primary color, as shown in Figure 9. For the diagonal matrix pixel pattern, the spatial sampling array for all three primary colors is the same.

The spatial frequency lattice of the color matrix display is determined next. This is found by taking the Fourier transform of the spatial sampling array. Nyquist theory is used to determine the bandpass characteristics of the reconstruction filter. Nyquist sampling theory states that the maximum frequency which can be displayed on a color matrix display, without creating aliasing, is one half of the sampling frequency. The boundaries for maximum displayable frequencies therefore fall midway between the lattice points of the spatial frequency array. These boundaries, called the Nyquist boundaries, are shown in Figure 10 for the diagonal matrix pattern. The Nyquist boundaries define the maximum frequency capability of the color mosaic in all directions. Therefore, the transfer function of the ideal bandpass filter for the diagonal pattern is as shown in Figure 11.

The next step is to determine the interpolation function to be used, with the extent of interpolation defined by the Nyquist boundaries. Figure 12 shows some possible interpolation functions which give acceptable results. The triangle function is one of the simplest, whereas some of the other functions, such as the cubic B-spline, give more accurate results. Figure 13A gives an example of a one-dimensional reconstruction using the triangle function. The higher order interpolations give better reconstruction of the signal. Ideally the sinc function (of the form sin(x)/x) would be used, as shown in Figure 13B.

Thus, a number of interpolation waveforms are possible as is shown in Figure 12, waveforms a, b, c, d, e and f. Resulting interpolations are shown in Figure 12, waveforms g, h and i. Given that the expanse of the diffracted pattern can be changed at will by the distance of the grating from the panel, it is decided what shape would offer the best overall performance. Based on theory and practice, a three dimensional cubic B-spline (or a close approximation to it) has been selected as the target shape, see Figure 12e. Over the proper interpolation distance, it connects each sample to its neighbors smoothly by ensuring continuity through the first and second derivatives. In this two- dimensional case the ratio of the long versus the short axis is determined by the diagonal pixel pattern itself.

Once the desired interpolation function has been chosen, the diffraction grating optical reconstruction filter is then designed to create the corresponding point spread function (PSF). The PSF of the diffraction grating is determined by the position and intensity of the various diffracted orders. The position and intensity of the diffracted orders is determined by the surface profile of the diffraction grating. The equations which relate the position and intensity of diffracted orders to the surface profile of a diffraction grating are standard diffraction equations. Of primary significance to the invention is that the surface profile of the grating controls the resulting PSF of the grating. By manipulating the surface profile, the PSF is varied and can be tailored to deliver the desired interpolation function. There are several ways of accomplishing this, including empirical, simulated annealing, or holographic techniques.

Figure 14 shows one embodiment of the invention, a phase diffraction grating designed for the RGBY

cubic B-spline, as shown in Figure 15.

Figure 15 shows the intensity profile of a pixel from a diagonal color mosaic display after it has undergone a cubic B-spline interpolation. This may also be described as the resultant pixel luminance profile when cubic B-spline interpolation is applied to diagonal color mosaic pattern. Thus in Figure 15 there is shown the original pixel size 40, the size of $\Delta a = 1.414$ pixels and of $\Delta b = 2.12$ pixels. The figure also shows the ratio of diagonal color mosaic

$= \frac{\Delta a}{\Delta b} = 1.414/2.12$. The orientation of the interpolation function can also be changed if desired. Figure 16 shows this grating over a panel and illustrates the interpolation and resulting smoothing of the sampled image.

The diffraction grating reconstruction filter can be used for any of the pixel patterns used with color matrix displays. In each case, by tailoring the filter to the lattice structure as explained above, the full frequency capability of each particular pattern is used. Frequencies beyond this capability are eliminated. The result is enhanced image quality on color matrix displays.

In Figure 8 there is shown the major axes a and b and the separation between same color pixels R, G, and B of diagonal color mosaic pattern. In this figure the interpolation function is oriented along the plus and minus 45 degree axes of the diagonal mosaic pattern. The separation between adjacent R pixels is shown to be $d_{a\text{-axis}} = \sqrt{(1\ \text{pixel})^2 + (1\ \text{pixel})^2} = 1.414$ pixels. On the other axis the separation between R pixels the separation is shown to be $d_{b\text{-axis}} = \sqrt{(1.5\ \text{pixels})^2 + (1.5\ \text{pixels})^2} = 2.12$ pixels.

The orientation of the interpolation function can also be changed to test questions about preferred axes of orientation of the target image. In the case of static characters, for example, which are predominately rendered with vertical and horizontal strokes, it may be desirable to orient the interpolation function vertically and horizontally rather than along the plus and minus 45 degree axes of the diagonal mosaic pattern (Figure 8). Though this extreme is not preferred, this and intermediate orientations can be evaluated by rotating the diffraction grating about an axis normal to the display surface.

In order to determine the surface profile of the diffraction grating, it is necessary to know exactly horn this profile controls the diffraction pattern. In determining the diffraction pattern of a particular grating, two factors need to be determined: 1) the lateral spacing of the orders, and 2) the light intensity (or relative efficiency) of the orders.

The lateral spacing of the orders is quite easy to determine. According to diffraction theory, the diffraction angle (the angle a diffracted order makes with respect to normal), $\alpha_p$, is given by the following equation:

$\sin \alpha_p = \frac{p\lambda}{X}$ (1)

where p is the order number, $\lambda$ is the wavelength, and X is the grating period in the x direction (see Figure 6A). The case of a viewer looking at a diffracted image is shown in Figure 4. Using Equation 1, the distance of an order from normal is determined to be

$$x = \frac{p\lambda t}{X} \qquad (2)$$

where t is the distance between the flat panel and the diffraction grating. This is easily extended to the two dimensional case, where the location of the orders is given by

$$x = \frac{p\lambda t}{X} \quad \text{and} \quad y = \frac{q\lambda t}{Y}, \qquad (3)$$

where q is the order number, and Y is the grating period in the y direction. The distance between any two adjacent orders is therefore given by

order spacing $\frac{\lambda t}{X}$, or $\frac{\lambda t}{Y}$. (4)

These equations can be used to estimate the range of grating frequencies necessary for flat panel applications. Assume a wavelength of 550 mm, and a 1 mm space between panel and grating. For a panel with a 0,015mm (6mil)pixel size, we can assume an approximate order spacing of 0,0025 - 0,015 mm (we will want to move the 1st order. image 0,0025 - 0,015 mm away from the zero order image). Inserting these numbers into Equation 4, the grating period will need to range from 3.6 to 22 x $10^{-3}$mm, giving a frequency range of 45 - 275 cycles/mm. The exact frequency is determined by the design of precisely how far the orders are to be moved.

In order to find the intensity of each of the orders a mathematical derivation of the Fraunhofer (far field) diffraction order efficiency for a two-dimensional grating has been derived. The efficiency, $n_{p,q}$, or relative intensity of each order is approximately:

$$n_{p,q} = \left| \frac{1}{XY} \int_X \int_Y e^{\left[2\pi i \left(\frac{px}{X} + \frac{qy}{Y}\right) - i\, w(x,y)\right]} \, dx\, dy \right|^2 \quad (5)$$

where w(x,y) is the phase shift introduced by passage through the grating, and is given by

$$w(x,y) = \frac{2\pi\,(n_o - n_1)\; s(x,y)}{\lambda} \quad (6)$$

where $n_o$ is the refractive index of the surrounding medium (usually air, $n_o = 1$), and $n_1$ is the refractive index of the grating material, and s(x,y) is the function which describes the surface profile of the diffraction grating.

One process for fabricating a diffraction grating with dichromated gelatin using photolithographic techniques is illustrated in Figure 17. A layer of photoresist material, such as dichromated gelatin, is spun or otherwise deposited onto a glass substrate. Then through a mask the photoresist material is exposed with uv light. The areas which have been exposed are washed away with water, leaving a surface profile of dichromated gelatin. In one example the mask used to prepare gratings has 100 lines/mm in both the x and y directions. Figure 18 shows the flat panel structure 41 and how the diffraction grating reconstruction filter (diffuser) 42 can be placed. The diffraction diffuser 42 here takes the form of a thin glass substrate, with a phase relief structure deposited upon it, placed over the last polarizer 43 in the flat panel stack. Beneath polarizer 43 is an upper substrate color filter 44, a common electrode 45, a spacer 46, the liquid crystal material 47 and the flat panel display 48 on the lower substrate 49. Polarizer 50 may be positioned beneath the lower substrate 49. Backlighting 51 is provided. A magnified section 52 of the diffuser 42 is shown in the balloon 53.

A drawing of a photograph of a grating fabricated with the 100 line/mm mask is shown in Figure 19. The circles are "wells" where the dichromated gelatin has been removed. Figure 20 shows the pattern created when a laser beam is passed through the grating. large throw distance was used to spread out the orders and illustrate their relative efficiencies. For flat panel use the diffraction grating is closely spaced to the panel so that the orders are all overlapping.

Thus, the present invention has entailed how one goes about specifying the filter requirements for a diffraction grating to operate as an optical reconstruction filter, when a particular flat panel liquid crystal color mosaic pattern is given. There is specified a method of determining filter cutoff requirements given any pixel pattern on the color matrix display; and there is specified the filter cutoff requirements in terms of each primary color lattice in the mosaic. The present invention is of a design to permit maximum use of available color mosaic spatial frequency capacity.

## Claims

1. A color matrix display apparatus comprising a matrix display having a viewing face and comprising a regular structure of pixels which are selectively energized to create an image, **characterized by:**
a two-dimensional diffraction grating reconstruction filter (10,20,31,42) positioned proximate and in front of said matrix display (30) viewing face which uses the phenomenon of diffraction to filter the image, the diffraction grating breaking each pixel image up into various diffraction orders in two-dimensions as it passes through the grating, whereby the diffracted pixels overlap and cause interpolation among the pixels thereby minimizing the high frequency energy and detection of the underlying grid structure and improving the image.

2. Apparatus according to claim 1, **characterized in that** the color matrix display is selected from types other than CRT technology.

3. Apparatus according to claim 1, **characterized in that** the color matrix display is of a type selected from the group consisting of liquid crystal, plasma panels, electroluminescent, and vacuum fluorescent displays.

crystal color matrix display (30).

5. Apparatus according to claim 4, **characterized in that** there are major axes (in x and y) of pixel pattern for same color pixels.

6. Apparatus according to claim 6, **characterized in that** said major axes for same color pixels is a diagonal matrix pattern.

7. Apparatus according to claim 5 or 6, **characterized in that** the axes of said two-dimensional diffraction grating is oriented to the major axes of the flat panel pixel pattern.

8. Apparatus according to claim 1, **characterized in that** the diffraction grating is a phase transmission grating.

9. Apparatus according to claim 8, **characterized in that** the phase transmission grating is a binary step type.

10. Apparatus according to claim 1, **characterized in that** the diffraction grating has a point spread function defined by the primary color's lattice structure of the color mosaic display.

11. Apparatus according to claim 1, **characterized in that** said two-dimensional diffraction grating reconstruction filter (31) positioned proximate and in front of said matrix display (30) viewing face has a spacing "t" therebetween, the controlling of the spacing allowing the extent of interpolation desired to be obtained.

12. Apparatus according to claim 4, **characterized in that** said liquid crystal display comprises a glass substrate and in which said two-dimensional diffraction grating is embedded as an integral component of said liquid crystal color mosaic display glass substrate.

13. Apparatus according to claim 4, **characterized in that** said grating is juxtaposed the surface of said liquid crystal color mosaic display.

14. A flat panel liquid crystal color matrix display stack assembly (41), comprising in combination:
backlight means (51);
first polarizer means (50);
a two-dimensional liquid crystal display means (49);
second polarizer means (43); and
a two-dimensional diffractive diffuser (42) spaced from said liquid crystal display by a spacing distance t so that an image of a point on said liquid crystal display is thereby diffractively diffused.

15. A method for designing a diffraction grating optical reconstruction filter for a color mosaic (or matrix) display comprising the steps:
providing a flat panel two-dimensional color matrix display having regular structures of color pixels of a plurality of primary colors, said flat panel display having an inherent underlying grid structure which results in objectionable visual artifacts in the display commonly referred to as sampling noise;
specifying each primary color lattice in the display;
determining lattice as defined by each primary color alone;
determining spatial frequency pattern of lattice by taking Fourier Transform;
determining Nyquist boundaries by,
from reference point drawing a ray to each nearest neighbor point,
at midpoint of each ray drawing a perpendicular line,
the region circumscribed is maximum frequency capability of the color mosaic display,
the collection of perpendicular bisectors comprise the Nyquist boundaries themselves;
select interpolation waveform, one dimensional;
making one dimensional waveform into two-dimensional waveforms by rotating it through two dimensions and by adjusting its relative extent in accordance with the shape of the region circumscribed by the Nyquist boundaries thereby defining the desired point spread function of the grating in combination with the eye;
making the grating have point spread function minus the impact of the eye; and,
placing the grating over the panel at a distance t.

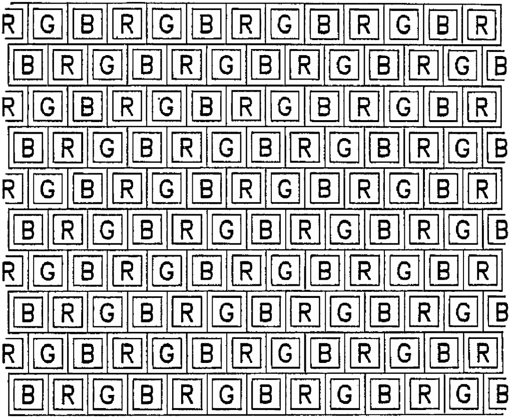

R G B R G B R G B R G B R
B R G B R G B R G B R G B
R G B R G B R G B R G B R
B R G B R G B R G B R G B
R G B R G B R G B R G B R
B R G B R G B R G B R G B
R G B R G B R G B R G B R
B R G B R G B R G B R G B
R G B R G B R G B R G B R
B R G B R G B R G B R G B

*Fig. 1*

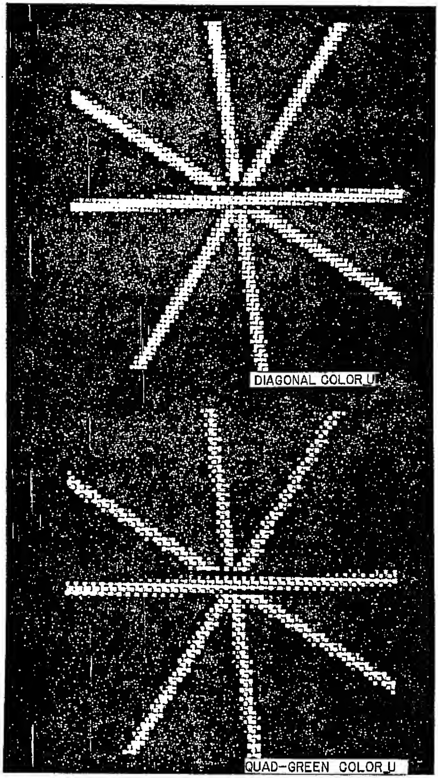



Fig. 2

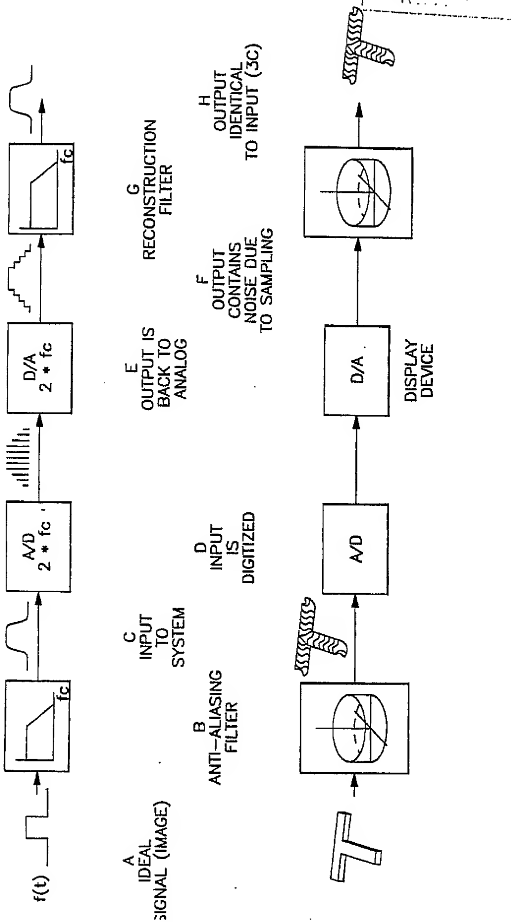

f(t)
A
IDEAL
SIGNAL (IMAGE)
fc
B
ANTI-ALIASING
FILTER
C
INPUT
TO
SYSTEM
A/D
2 * fc
D
INPUT
IS
DIGITIZED
D/A
2 * fc
E
OUTPUT IS
BACK TO
ANALOG
F
OUTPUT
CONTAINS
NOISE DUE
TO SAMPLING
fc
G
RECONSTRUCTION
FILTER
H
OUTPUT
IDENTICAL
TO INPUT (3C)
A/D
D/A
DISPLAY
DEVICE

*Fig. 3*

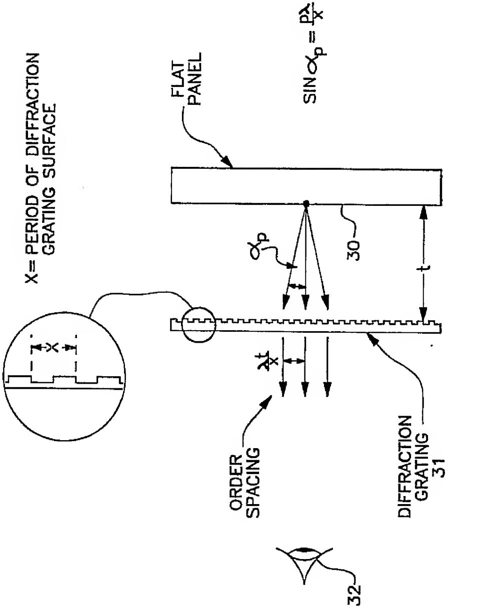
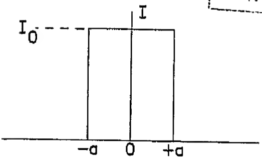

X= PERIOD OF DIFFRACTION GRATING SURFACE
X
FLAT PANEL
SIN $\alpha_p = \frac{p\lambda}{x}$
$\alpha_p$
30
t
$\frac{\lambda t}{x}$
ORDER SPACING
DIFFRACTION GRATING 31
32

*Fig. 4*

Fig. 5a




ORIGINAL PIXEL LUMINANCE PROFILE

Fig. 5b

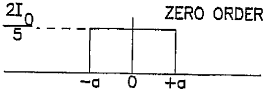



Fig. 5c

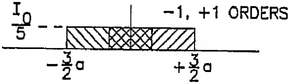
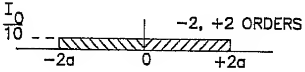
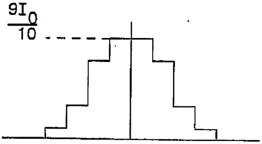



Fig. 5d

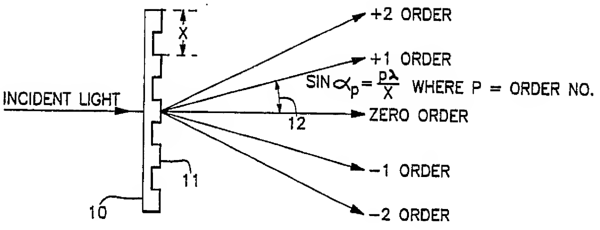



DIFFRACTED PIXEL ORDERS:
RELATIVE POSITIONS AND INTENSITIES

Fig. 5e

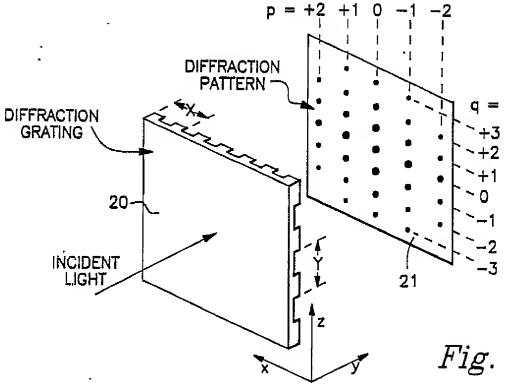



DIFFRACTED PIXEL
LUMINANCE PROFILE



X
+2 ORDER
+1 ORDER
SIN $\alpha_p = \frac{p\lambda}{X}$ WHERE P = ORDER NO.
INCIDENT LIGHT
ZERO ORDER
12
-1 ORDER
11
10
-2 ORDER


*Fig. 6a*



p = +2 +1 0 -1 -2
DIFFRACTION PATTERN
X
q =
+3
+2
+1
0
-1
-2
-3
DIFFRACTION GRATING
20
INCIDENT LIGHT
Y
21
z
x
y


*Fig. 6b*

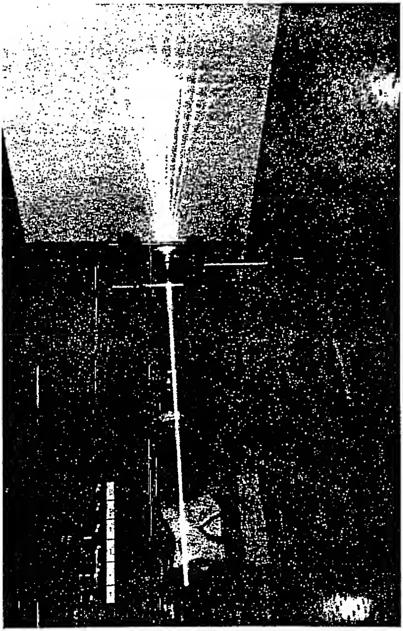


Fig. 7

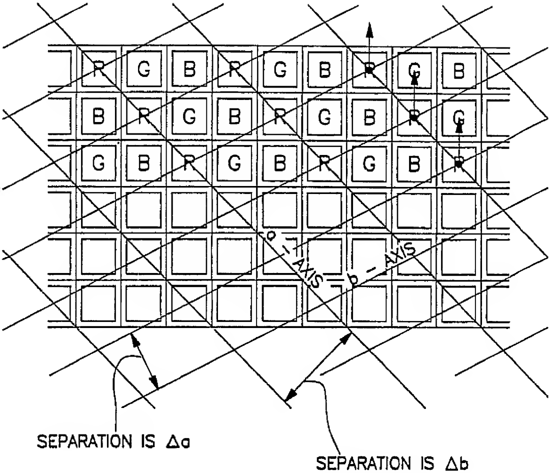
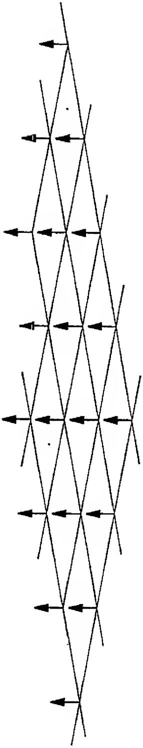
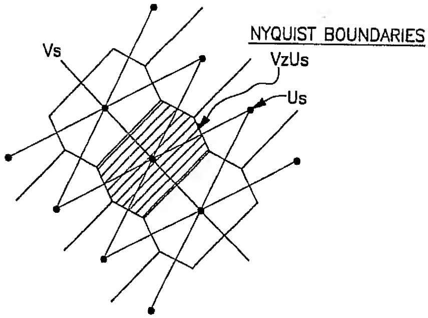

R G B R G B R G B
B R G B R G B R G
G B R G B R G B R
a – AXIS
b – AXIS
SEPARATION IS Δa
SEPARATION IS Δb

*Fig. 8*



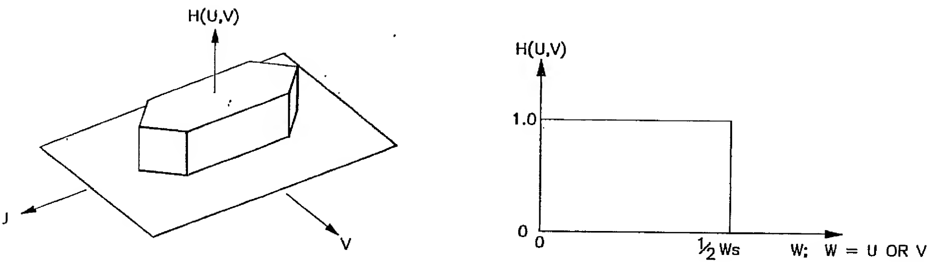
SPATIAL SAMPLING ARRAY FOR
DIAGONAL PATTERN
SINGLE PRIMARY COLOR

*Fig. 9*



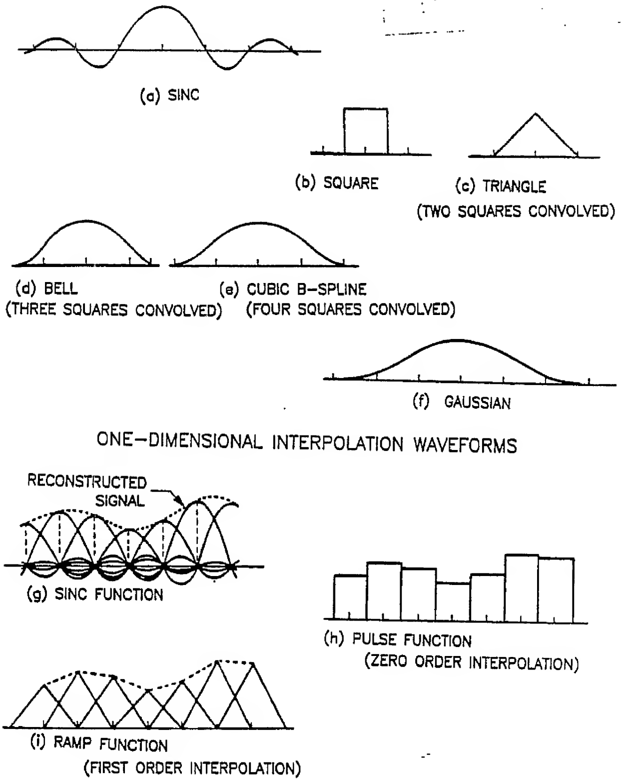

SPATIAL FREQUENCY ARRAY FOR
DIAGONAL PATTERN ISLANDS
OF RECOVERABLE FREQUENCIES

*Fig. 10*




IDEAL LOW PASS TRANSFER FUNCTION
FOR DIAGONAL PATTERN

*Fig. 11*




ONE DIMENTIONAL INTERPOLATION

*Fig. 12* POSSIBLE INTERPOLATION WAVEFORMS AND THE RESULTING INTERPOLATIONS

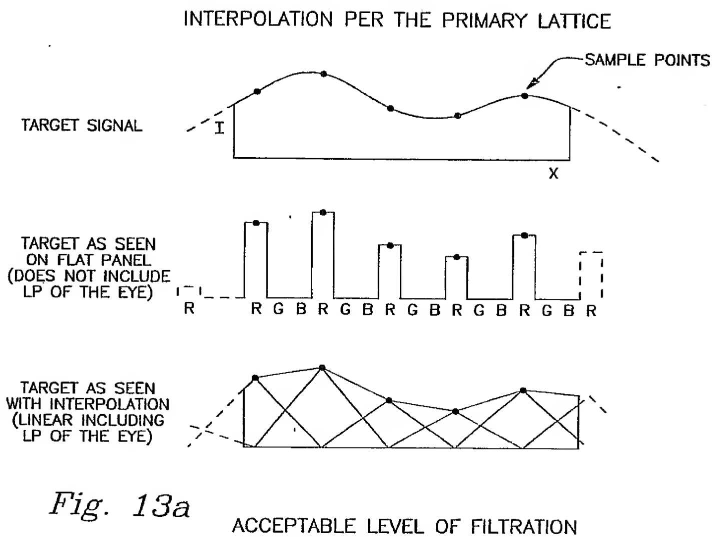

INTERPOLATION PER THE PRIMARY LATTICE
SAMPLE POINTS
TARGET SIGNAL
I
X
TARGET AS SEEN ON FLAT PANEL (DOES NOT INCLUDE LP OF THE EYE)
R
R G B R G B R G B R G B R G B R
TARGET AS SEEN WITH INTERPOLATION (LINEAR INCLUDING LP OF THE EYE)
ACCEPTABLE LEVEL OF FILTRATION

*Fig. 13a*

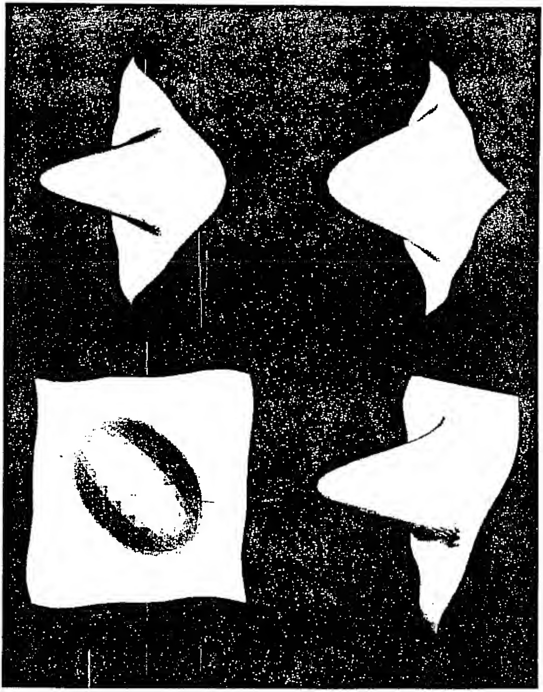


Fig. 13b

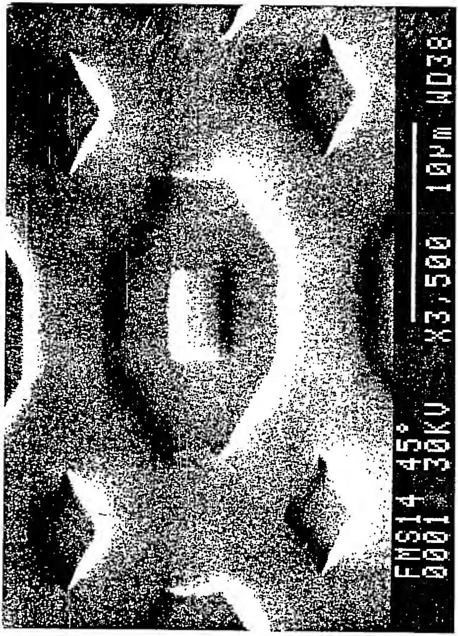



Fig. 14

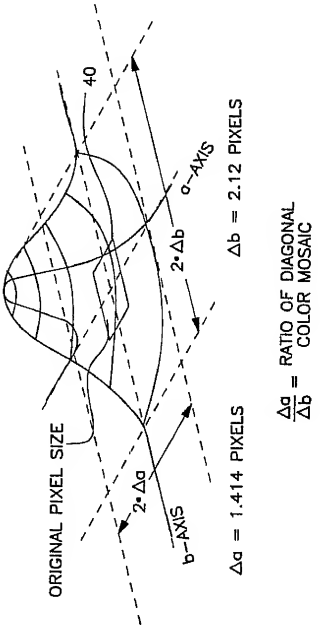

40
a–AXIS
b–AXIS
2•Δb
2•Δa
ORIGINAL PIXEL SIZE
Δa = 1.414 PIXELS
Δb = 2.12 PIXELS
$\frac{\Delta a}{\Delta b}$ = RATIO OF DIAGONAL COLOR MOSAIC

*Fig. 15*

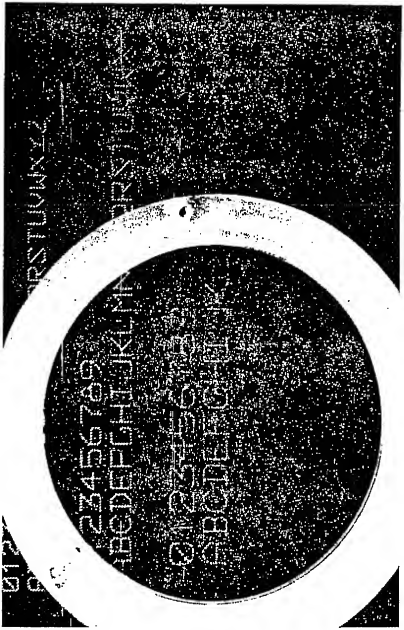


Fig. 16

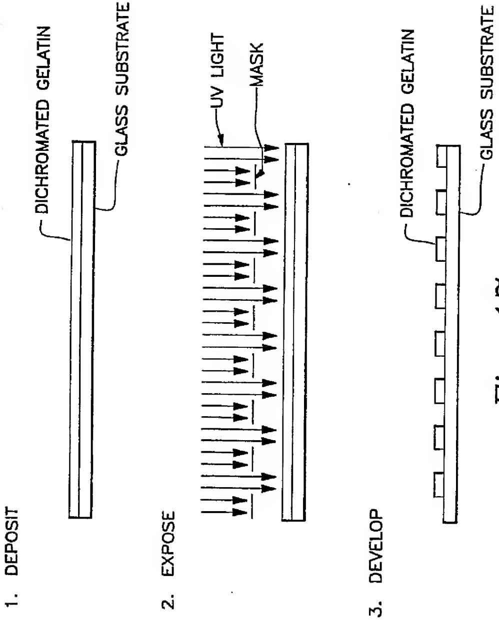
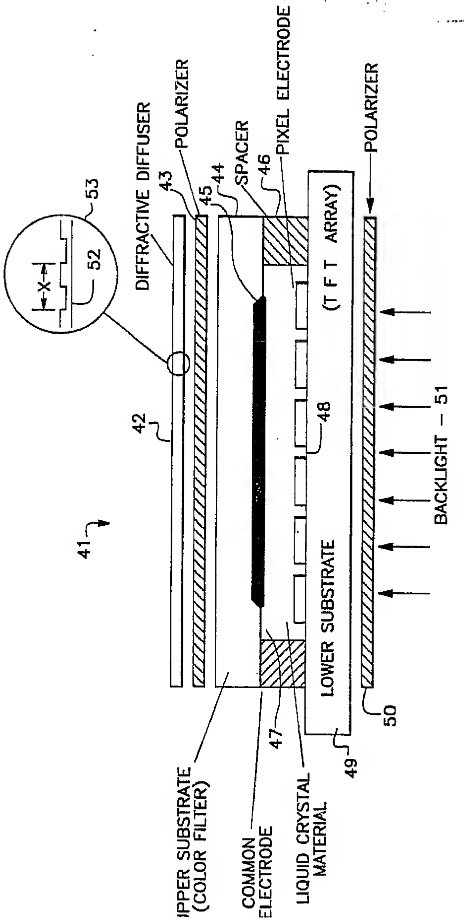

1. DEPOSIT
DICHROMATED GELATIN
GLASS SUBSTRATE
2. EXPOSE
UV LIGHT
MASK
3. DEVELOP
DICHROMATED GELATIN
GLASS SUBSTRATE

*Fig. 17*



DIFFRACTIVE DIFFUSER
POLARIZER
SPACER
PIXEL ELECTRODE
POLARIZER
(T F T ARRAY)
LOWER SUBSTRATE
BACKLIGHT — 51
IPPER SUBSTRATE (COLOR FILTER)
COMMON ELECTRODE
LIQUID CRYSTAL MATERIAL
41
42
43
44
45
46
47
48
49
50
52
53
X


Fig. 18

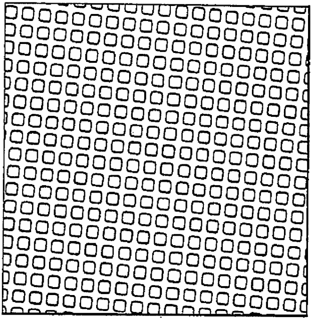


Fig. 19

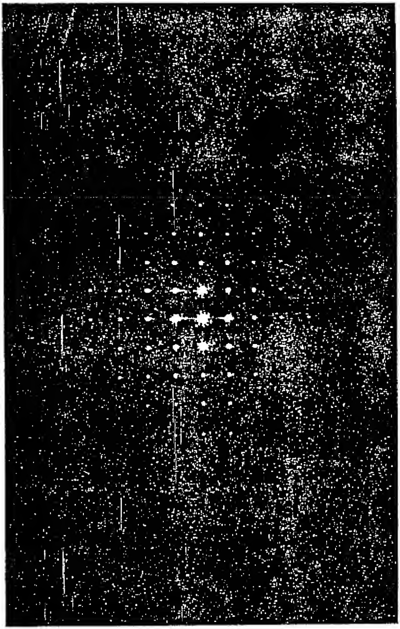


Fig. 20